Progress Report on Study of Technical Issue and R & D for IFE

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Technical Issues and R & D Study

Objectives

- Based on experience from PROMETHEUS-L and H Designs:
  - Identify and Characterize key Technical Issues for IFE
  - Identify key areas of R & D (facilities, cost, time)

Remarks

- This task is scheduled for the next quarter. However, we have already made very significant progress. Most critical issues have been documented.

- Identifying Technical Issues and R & D is of tremendous value

  It Translates Design Study into a <u>useful</u> and <u>useable</u> product:
  - For DOE: provide technical input for programmatic decisions on R & D
  - For Technical Community: Guide and Stimulate further work.

Presentation

- Highlight Progress only (<u>not</u> detailed description)

- Technical Details should be part of a workshop in March.

What is an Issue?

- Many uncertainties exist in actual performance and operation of present IFE Conceptual Designs

- Expected Consequences of these issues vary:

  - One extreme: Uncertainties are so large that the Feasibility of the reactor design is at stake

  - Other extreme: Uncertainties may require only moderate redesign or reduce performance

- Classification of Separate issues: somewhat arbitray; many technical disciplines and phenomena are interrelated.

<u>This Study</u>

Emphasis on
- most important issues
- Testing Issues: those that require experiments

Classification
- Key Issues
- Critical Issues

Key Issues

- Many in number, somewhat narrow and specific in technical focus

- categorized by component

- Basis for defining R & D (testing) needs

Critical Issues

- Smaller in number, highest priority
- Purpose is to convey the sense of critical problems in IFE
- Each critical issue tends to be broad and may encompass several key issues, which as a group form a critical problem.

IFE CRITICAL ISSUES

1. Demonstrating Moderate GAIN at LOW Driver Energy

Developing physics and engineering test facilities of affordable small to moderate size (fusion power <100 MW) is crucial for an IFE R & D pathway that is practical in terms of cost and time. Ignition (or moderate Q) at low driver energy (<1MJ) is the key.

2. Feasibility of Direct Drive Target System

- Physics of implosion
- Target Illumination Requirements
- Efficiency of coupling driver energy into the target
- Target injection and tracking

Present data on DD targets is at only a few KJ of Laser energy. Need data at 100's of KJ to Migajoule.

3. Feasibility of Indirect Drive Targets For Heavy Ion

- properties of the method used to transport HI beam to the target
- accuracy and reproducibility of the repetitive HI target launch system to the center of the target chamber
- ability of the high-Z Hohlraum cavity to convert incident radiation on the D/T capsule

4. Feasibility of Indirect Drive Targets For Lasers

- accurate target tracking and pointing of the multiple laser beams to coincide with the two entrance apertures of the moving ID target

- accurate and reproducible indirect drive target propagation from the pellet factory to the center of the target chamber

- overcoming the problems of plasma closure of the two entrance apertures to the Hohlraum

5. Feasibility of Cost Reduction Strategy for the Heavy Ion Driver

Technical Feasibility of HI driver is assured. Present cost (billions of dollars) is too high. Two key key issues for cost reduction.

1) Space charge limited transport of a bunched beam
2) High current storage rings for heavy ion beams

6. Demonstration of High Overall Laser System Efficiency

The major problem is the Excimer Laser Amplifiers. The major obstacle is the lack of previous work on moderate-sized (2-4KJ output) excimer laser amplifier modules R & D program with the goal of producing a 2 to 4 KJ excimer laser amplifier with a wall plug efficiency of 12% (and a mean time between failures of between 10^9 and 10^{10} shots) is required.

7. Tritium Fuel Self Sufficiency

Self-sufficiency condition: $\Lambda_a \geq \Lambda_r$

<u>Achievable TBR</u>

- Uncertainties in design: wall coverage, amount of structural materials, wall protection scheme, blanket details

- Uncertainties in prediction capabilities: nuclear data, geometric modelling in neutron transport

<u>Required TBR</u>

- Uncertainties in tritium mean residence time in components of the fuel cycle, e.g. in target factory

- efficiency of tritium extraction in various parts of the fuel cycle

8. Cavity Clearing for High Repition Rate (~ 5-10 Hz)

- Propagation limits for both targets and driver energy
- requirements on background gas pressure for protection of the first wall (and final optics)
- achievable chamber pressure
  (Physics of energy and mass transport and vapor recondensation)
- Vacuum System Requirements
  (size of ducts affects blanket coverage and radiation streaming)

9. Laser Optics Performance, Reliability and Lifetime

- GIMM Thermo-mechanical and Material Design
  - radiation load (nuclear heating and fluence)
  - thermal deformation
  - inelastic structural analysis
  - thermal stress/fatigue

- Dielectric Turning Mirror
  - Pinhole Design and neutron fluence
  - radiation limits

10. Viability of Liquid metal Film Flow for Wall Protection System

- Film Flow Stability Analysis
- Stabilization Methods, film Thickness control, wetting
- Difficult Problems near inverted surfaces (e.g., upper hemisphere and tops of beam lines)

11. Manufacturing, Reliability and Lifetime of Silicon Carbide Structures

- Manufacturing Methods and costs
- Radiation effects and Fatigue Life (swelling, embrittlement, fiber shrinkage and/or detachment from the matrix, creep crack propagation, and crack bridging)

12. Radiation Shield Design for Protection of Final Optics and for Personnel Access

- Accuracy of predicting neutron transport in specialized geometry
- Minimizing collided neutron flux at Final optics
- economical shield that minimizes activation in the reactor building, permits personnel access within days after shutdown without impeding maintenance

13. Reliability and Lifetime of Laser and Heavy Ion Drivers

14. Demonstration of Non-Linear Optical Laser Driver Architecture

R & D Needs

Reasons For Carrying out R & D Assessment

The identified R &D will serve 3 purposes:

1) Provide Programmatic-Decision Makers (OFE) with a list of important R & D tasks that need to be carried out

2) Provide part of the input for comparison between Heavy-Ion and Laser-Driven Reactors

3) Identify R & D common to IFE and MFE

R & D for What?

- R & D is to be identified for each separate key issue or for a group of the key issues (For key issues, not limited to critical issues)

- R & D to resolve the issue or group of issues in order to provide adequate data base for the design and construction of IFE Experimental Power Reactor (IEPR)

- What is IEPR ?
  - ITER - like device for inertial fusion energy. It provides the data base for DEMO
  - We do not know parameters yet
  - Guidance (very approximate guess)
    - Fusion Power ~ a few hundred Megawatts
    - Rep. Rate ~ one per second
    - availability ~ 25 - 35 %
    - Prototypical components and system integration

R & D Write -up

[What team members must provide for each issue or group of issues]

Issue: Give title and number for the issue(s) that this R & D is intended to resolve. (The issue number and title are from the issue section write-up. If you combine a number of issues provide a single title here and put all numbers of all issues involved)

Description

Concise description of the R & D effort to be performed. Effort can be modelling and/or experimental. Provide description sufficient to understand the kind of work to be done without getting very detailed.

Facility

Indicate whether a new facility is needed or an existing facility can be used. For a new facility provide description of general features.

Cost and Time

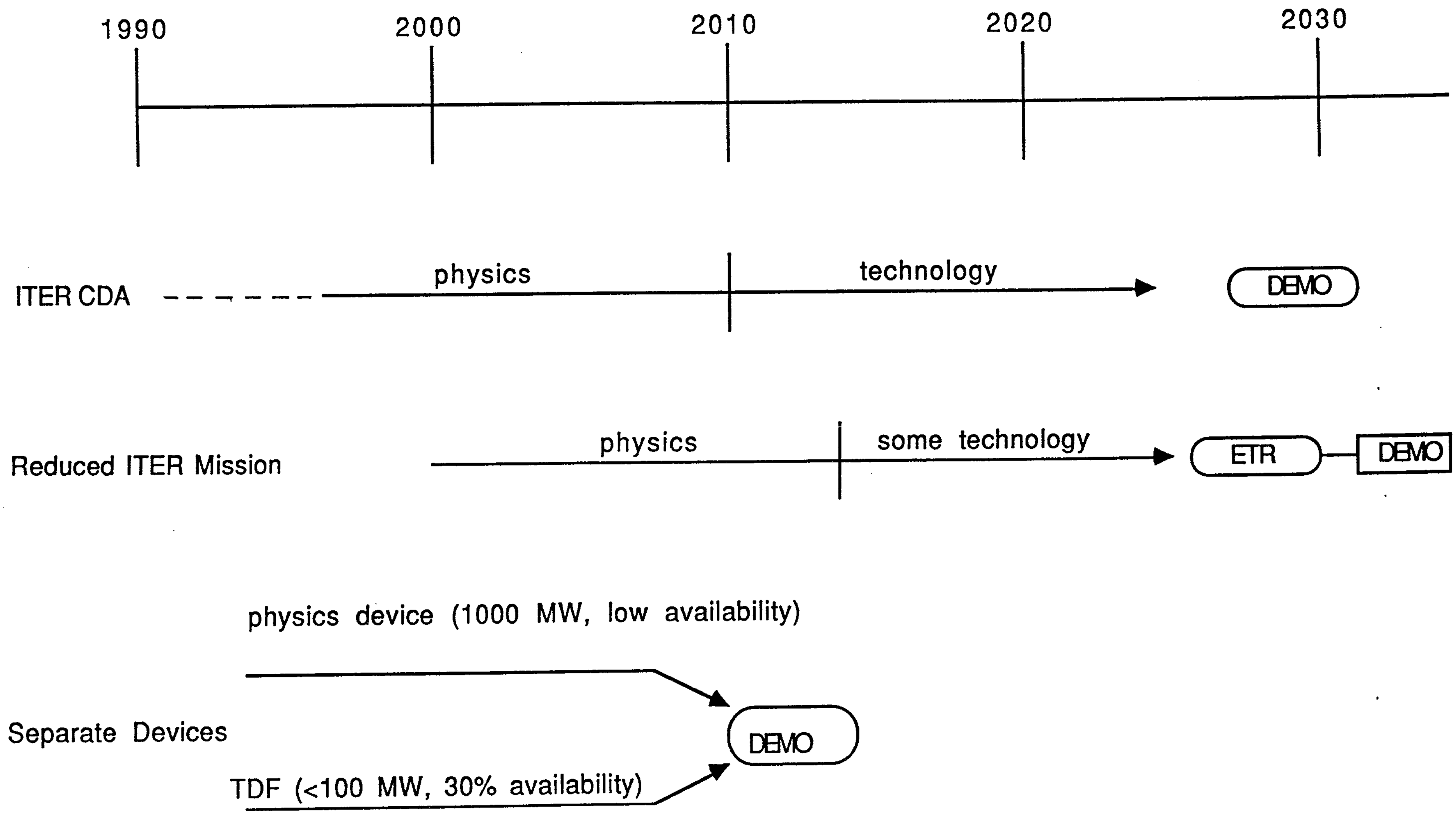
Capitol Cost: in millions of dollars (for new facility or an upgrade only)

Annual Operating Cost:
total operating cost per year including facility operation, experiments, and manpower.

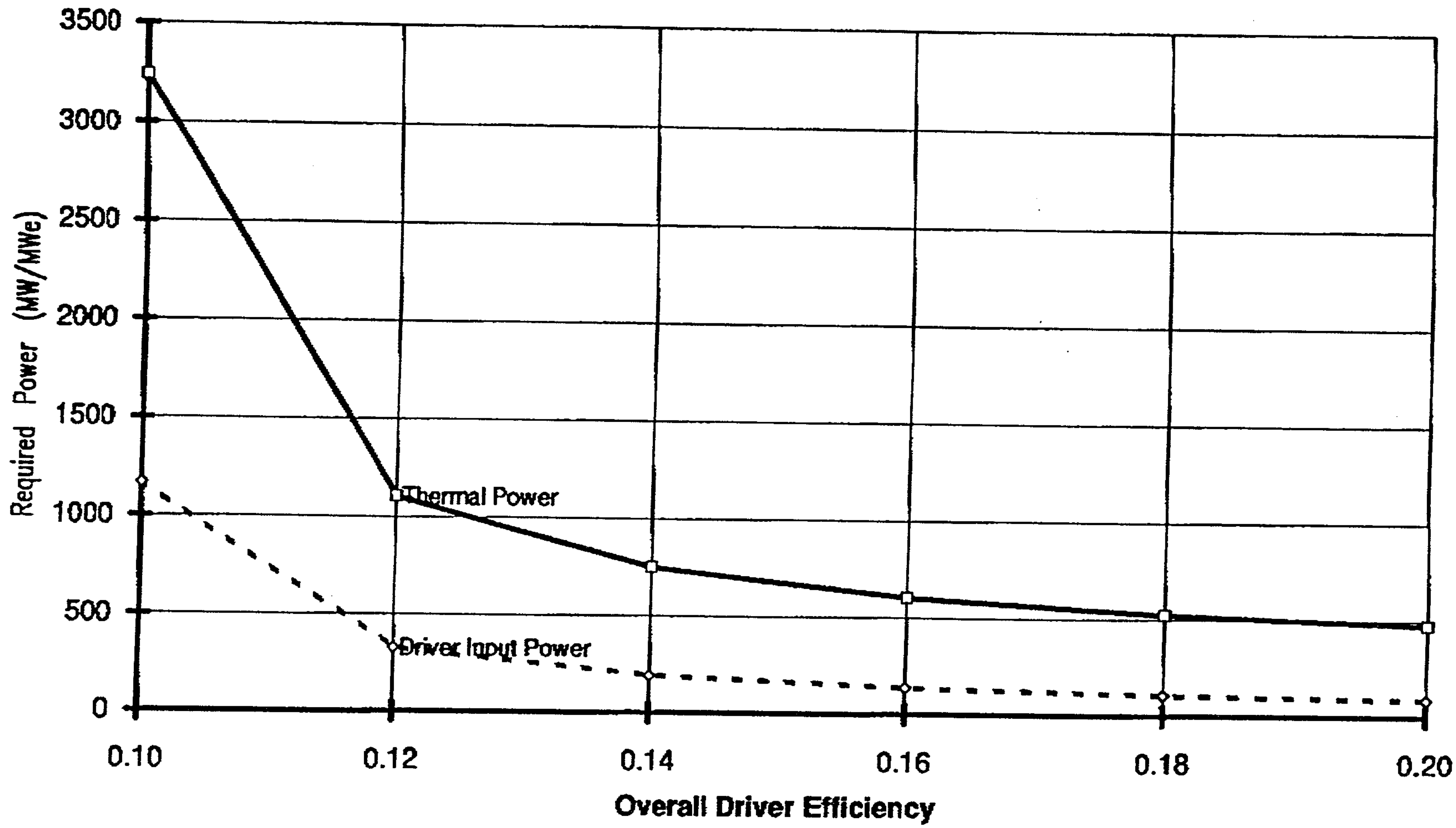
Time: time in years required to complete this R & D

Alternative Pathways to DEMO

(Schematic for illustration purposes only; need to check time schedule, add other fusion and non-fusion devices including devices in the 1990's)



DEMO SIZE DEPENDS STRONGLY ON DRIVER EFFICIENCY
(100 MWe; 1.5 MJ Driver; 1.3T_imf Gain Curves)



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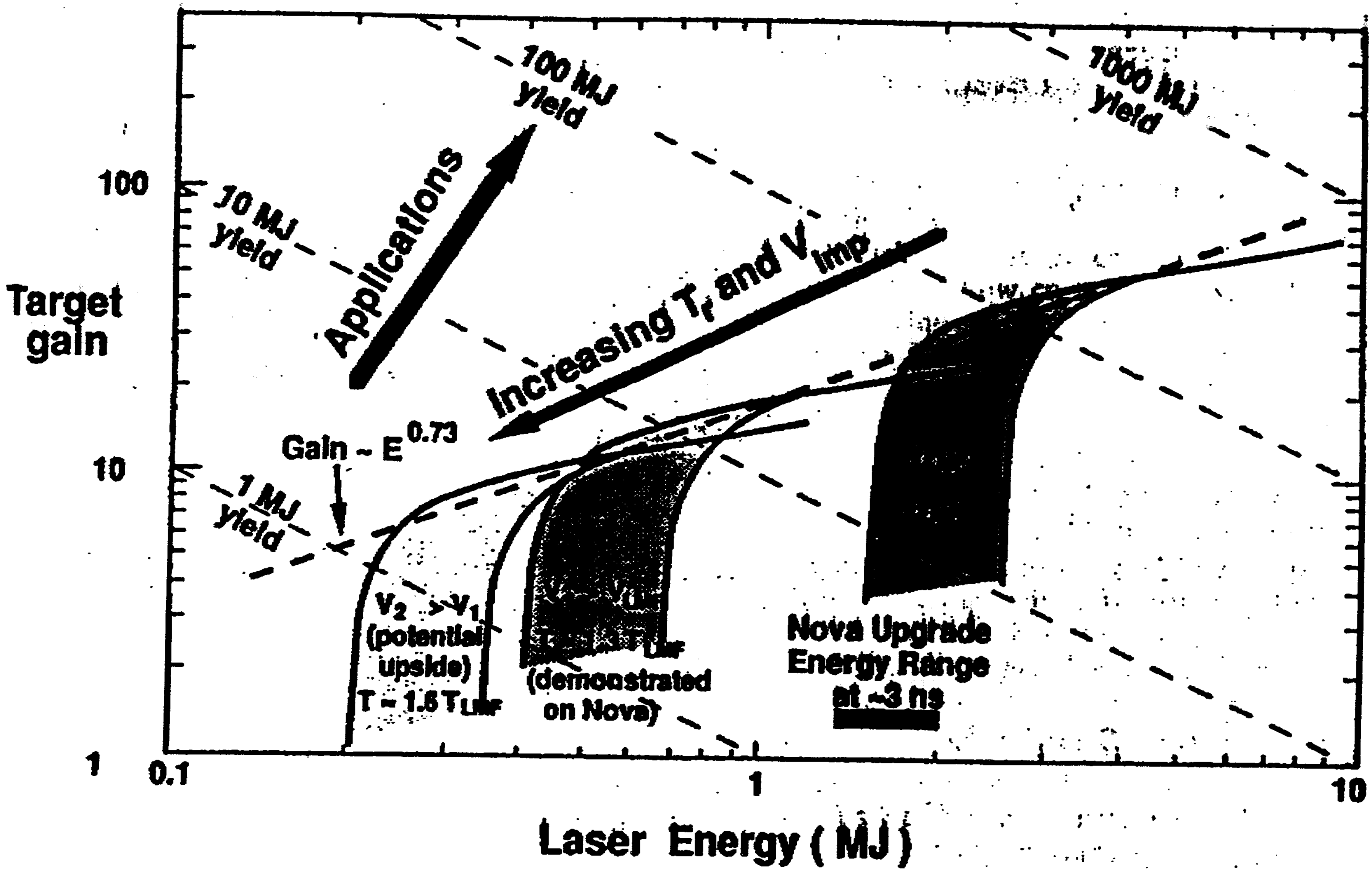

Fig. 1 Gain predictions for various hohlraum temperatures. The Nova Upgrade will reveal how well we can predict and control the location and height of the ignition "cliff"

IFE Issues Summary Table

Issue/Technical Area	Reactor Concept	Potential Impact	Design Specifity	Level of Concern	Operating Environment		Relevance to MFE
					Neutron	Parameters	
A) Target							
A.1.Direct Drive Target Coupling	L/HI	DW,UL, RP	Generic	Critical		H,,L,TWI,G ,N	None
A.2 Survivability of Targets in Chamber Environment	L/HI	DW,RP	Generic	High		S,T,A,G,Q,t ,q,P,v	Low
A.3 Demonstration of Injection and Tracking of Targets Coupled with Beam Steering	L/HI	UL	Generic	Critical		A,TWI,P	Low
A.4 Manufacturability of High Quality, Low Cost DD and ID Targets	L/HI	UL,RP,IC ,RS	Generic	High		H,TWI,N	Medium
B. Driver							
B.1 Laser							
B.1.1 D/T Target Illumination	L			High			
B.1.2 Large Laser Bandwidth	L			High			
B.1.3 Final Optics Pointing System	L			High			
B.1.4 Grazing Incidence Mirror Damage	L			High			

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Issue/Technical Area	Reactor Concept	Potential Impact	Design Specifity	Level of Concern	Operating Environment Neutron	Operating Environment Parameters	Relevance to MFE
B.1.5 SBS Pulse Compressore	L			High			
B.2. Heavy Ion							
B.2.1 Timing of Heavy Ion Beam	HI			High			
B.2.2 Channel Formation	HI			High			
B.2.3 Channel Transport	HI			High			
B.2.4 Stripping of HI Beam	HI			High			
B.2.5 Alignment of Indirect HI Target	HI			High			
C. Tritium Processing System							
C.1 Tritium Inventory Mean Residence; Time of Tritium in the Subsystems; Tritium Losses from the Sub-systems	L/HI	RS	B.T. Target Factory	Medium			High

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Issue/Technical Area	Reactor Concept	Potential Impact	Design Specifity	Level of Concern	Operating Environment Neutron	Operating Environment Parameters	Relevance to MFE
D. Cavity							
D. 1 Wall Protection							
D.1.1 Cavity Vapor Hydrodynamics	L/HI	DW,UL	Generic	Critical		S,A,G,TWI, Q,t,q,p	None
D.1.2 Cavity Structure Mechanics	L/HI	UL,RP,IC	All	High		F,T,s,A,TW I,G,Q,q,P,N ,s	Low
D.1.3 Vapor Condensation Rate	L/HI	DW,RP, IC	Wall Design	Critical		T,A,TWI,G, t,q,P	None
D.1.4 Radiation Heat Transport in Partially-ionized Gas	L/HI	RP,RL	Generic	High		T,A,TWI,G, Q,t,q	Low
D.1.5 Film Flow Control: Injection, Uniform Thickness and Drainage	L/HI	DW	Generic	Critical		A,G,v	Low
D.1.6 Film Flow Stability and Response to Impulsive Loading	L/HI	DW	Thin Film	High		A,G,v	Low
D.1.7 Pb/Sic Wettability	L/HI	RP,RL,IC	Specific	Medium		C,I,s	Low
D.1.8 Pb Compatibility with Steel	L/HI	RP,RL,RS	Specific	Medium		T,C,v	Medium

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Issue/Technical Area	Reactor Concept	Potential Impact	Design Specifity	Level of Concern	Operating Environment		Relevance to MFE
					Neutron	Parameters	
D.2 Blanket							
D.2.1 Tritium Self-Sufficiency	L/HI	DW	All	Critical			High
D.2.2 Tritium Inventory, recovery, and containment	L/HI	US	SB	Critical	R,H	Pt, T,C	High
D.2.3 Breeder/Structure Mechanical Interactions	L/HI	RL	SiC,SB	High	D	P,σ,T,N,t,s	High
D.2.4 Off-normal and Accident Conditions	L/HI	US	SiC	High	D	P,σ,T,N	High
D.2.5 Structural Response and Failure Modes	L/HI	RL	SiC	High	D	P,σ,T,N	Medium
D.2.6 Corrosion and Mass Transfer	L/HI	RP	SB	Medium	R	F,T,C	High
D.2.7 Fabrication	L/HI	UL	SiC	Critical		A,G	Medium
D.2.8 Power Conversion and Efficiency							

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Issue/Technical Area	Reactor Concept	Potential Impact	Design Specifity	Level of Concern	Operating Environment Neutron	Operating Environment Parameters	Relevance to MFE
D. Cavity							
D.3 Shield							
D.3.1Effective of Bulk Shield							
D.3.1.1 Biological dose during operation and maintenance	L/HI	RS,UL	FW,B,S	High	R	ϕ,F,S,G	High
D.3.1.2 Radiation Streaming	L/HI	RS,US	FW,B,S	High	R	ϕ,F,S,G	High
D.3.1.3 Protection of sensitive components	L/HI	RL,IC,RS	FW,B,S	High	D,R	ϕ,F,S,G	High
D.3.1.4 Analytical techniques and data base	L/HI	Rl,IC,RS	Generic	High	R	ϕ,,S,G	High
D.3.2 Shield Compatibility with cavity and vacuum boundary, including assembly/disassembly	L/HI	RS,IC,RP	FE,B,S,V	Medium	H,R,D	ϕ,F,S,F,T	High
D.3.3 Activation of reactor building components outside the cavity	L/HI	US,RP, RL,IC	Generic	Low	R	ϕ,S,G	High
D.3.4 Shielding of final mirrors	L	UL,RP, RL,IC	Mirror	High	D,R	ϕ,F,S,G,T	None
D.3.4.1 Damaget to GIMMS	L	UL,RP, RL,IC	Mirror	High	D,R	ϕ,F,S,G,T	None
D.3.4.2 Damage to turning mirrors	L	UL,RP, RL,IC	Mirror	High	D,R	ϕ,F,S,G,T	None
D.3.4.3 Dose at laser windows	H	UL,RP, RL,IC	Magnets	High	D,R	ϕ,F,S,G,T	Medium
D.3.5 Shielding of quadrupole magnets							

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IFE Issues Summary Table(Con't)

Issue/Technical Area	Reactor Concept	Potential Impact	Design Specifity	Level of Concern	Operating Environment: Neutron	Operating Environment: Parameters	Relevance to MFE
E. Materials							
E.1 Viability of SiC							
E.1.1Radiation effects							
E.1.1.1 Displacement damage	L/HI	RL	FW,B	Medium	Required	ϕ,F,T,t	High
E.1.1.2 Swelling	L/HI	UL	FW,B	High	Required	ϕ,F,T,t	High
E.1.1.3 Creep fracture	L/HI	RP	FW,B	Medium	Required	ϕ,F,T,t	High
E.1.1.4 Mechanical properties	L/HI	RL	FW,B	High	Required	ϕ,F,T,t	High
E.1.5.Fracture toughness	L/HI	RL	FW,B	High	Required	ϕ,F,T,t	High
E.1.2Fatigue Life							
E.1.2.1 Crack Nucleation	L/HI	DW,UL	FW,B	High	Required	ϕ,F,T,σ	Low
E.1.2.2 Crack growth	L/HI	DW,UL	FW,B	High	Required	ϕ,F,T,σ	Low
E.1.2.3 Mechanical loading	L/HI	DW,UL	FW,B	High	Required	P,t	Low
E.1.3 Manufacturing							
E.1.3.1 Fibers	L/HI	IC,UL	FW,B	High	None	T,t	High
E.1.3.2 Matrix	L/HI	IC,UL	FW,B	High	None	T,t	High
E.1.3.3 Component	L/HI	IC,UL	FW,B	High	None	T,t	High
E.2 Structural Desin of GIMM							
E.2.1 Thermal deformations	L	DW,RP	LS	High	Required	ϕ,ϕt,T,p	None
E.2.2 Inelastic structural analysis	L	DW,RP	LS	High	Required	ϕ,ϕt,T,P	None
E.2.3 Segmentation and Piezoelectric control	L	DW,RP	LS	High	Required	ϕ,ϕt,T,P	None
E.2.4 Thermal stress/fatigue	L	DW,RP	LS	High	Required	ϕ,ϕt,T,P	None
E.3 Dieletric turning mirror							
E.3.1 Pinhole design and n fluence	L	RP	LS	Medium	Required	ϕ,ϕt,γ	None

IFE Issues Summary Table (Con't)

Issue/Technical Area	Reactor Concept	Potential Impact	Design Specifity	Level of Concern	Operating Environment Neutron	Operating Environment Parameters	Relevance to MFE
E.3.2 Radiation limits	L	RP	LS	Medium	Required	$\phi,\phi t,\gamma$	None
E.3.3 Materials analysis for solutions	L	RP	LS	Medium	Required	$\phi,\phi t,\gamma$	None
G. Safety and Environment							
G.1 Overall plant tritium inventory	L/HI	IC,RS	T	Medium	Required	H	Medium
G.2 Permeation of tritium	L/HI	RP,RS	T	Medium	Required	H	Medium
G.3 Normal operation tritium release	L/HI	IC,RS	T	Medium	Required	H	Medium
G.4 Neutronic cross sections/data library for activation analysis	L/HI	US	Generic	High	Required	F,ϕ,S,Q,γ	High
G.5 Removing decay heat from lead coolant under accident conditions	L/HI	US,IC, RS	FW	Medium	Required	F,ϕ,S,Q,γ	Medium
G.6 Hydrogen burn due to rupture of diffusion vessel	L/HI	RP,IC,RS	TF	Medium		H,P^T	None
G.7 Detection of local dry spots prior to failure	L/HI	US,IC	FW	High		F,ϕ,S,T,Q,σ	High

IFE Issues Summary Table (Con't)

Issue/Technical Area	Reactor Concept	Potential Impact	Design Specifity	Level of Concern	Operating Environment		Relevance to MFE
					Neutron	Parameters	
G.8 Detailed accident analysis	L/HI	IC,RS	All	High	-	All	Medium
G.9 Removal of contaminants from the liquid lead	L/HI	RP,RS	FW	Medium	-	I	None
G. 10 Impact of large quantities of lead on waste disposal	L/HI	IC,RS	FW	Low	-	I	None
H. Subsystem Interactions							
H.1 Laser system/cavity interface and final mirror protection	L	UL	D	Critical	Required	F,OF,S,C,T, n,γ,V,s,q	Low
H.2 SiC/Metal piping transition interface	L/HI	IC	Ceramic structure/ conventioal BOP	Critical	-	C,T,H,A,P, Q,I,v	High
H.3 Heavy-ion system/ cavity interface and beam propagation, focusing and optics	HI	DW	DH,WP	High	-	P,Q,IB,G,N ,T,E,EI,p	Low